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(72) Inventors WILLIAM LAWRESON ADAMS, MICHAEL PETER GRANT and RICHARD WRIGHT HICKMAN

(54) IMPROVEMENTS IN OR RELATING TO PROCESS CONTROL

(71) We, INDUSTRIAL NUCLEONICS CORPORATION, a corporation organised and existing under the Laws of the State of Ohio, United States of America, of 650 Ackerman Road, Columbus, Ohio 43202, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates generally to process control systems and methods wherein an adaptive control parameter is derived in response to measurements made at points along the process stream. The technique of the invention will be particularly described in relation to control of the manufacture of sheet materials, such as paper, but it is not limited to this application.

Process controllers in the prior art have generally been responsive to deviation of the product manufactured from a set point or target value. In many instances, however, it is desirable to maintain a property of the product as close as possible to a limiting value. One system for maintaining the value of a property of a product being manufactured as close as possible to a limiting value is disclosed in patent specification No. 1,250,196. In that specification, a limiting value for the property of the product is set and control is established in response to the standard deviation of the product and the limit. While that invention can be readily employed to control many processes, it requires relatively complicated apparatus for calculating the statistical variance or standard deviation, and for making the special compensating calculations required where abnormal distributions are encountered.

It is an object of this invention to make the computation of statistical standard deviation unnecessary.

According to the present invention, there is provided a method of controlling a variable property of the product or output of a manufacturing process or step, wherein the fraction of the product being produced in respect of which the property value falls outside a selected reject limit value is determined and utilised to maintain said fraction substantially constant.

It will be understood that the term "fraction" as employed here are in the appended claims means the amount of the product falling outside said selected reject limit during a particular period of time divided by the total amount of the product produced in that period of time.

The invention further provides a method of controlling a variable property of the product or output of a manufacturing process or step, wherein the target or set point value for the property is changed in accordance with changes in the fraction of the total product being produced in respect of which the property value falls outside a selected reject limit value, the target value being shifted toward the reject limit when said fraction falls and shifted away from the reject limit when said fraction rises, in such manner as to tend to keep said fraction substantially constant.

Also according to the invention, there is provided a system for controlling a variable property of the product or output of a manufacturing process or step, comprising means monitoring the value of the property for deriving a fraction defective signal indicative of the actual fraction of the product having a property value outside of a selected reject limit, means comparing said fraction defective signal with a signal indicative of a selected

point for the fraction for deriving an error signal, and means responsive to the error signal for controlling the magnitude of a target value for the property in such a manner that the target value for the property is varied to approach the reject limit in response to the actual fraction being less than the fraction set point and to recede from the limit in response to the actual fraction being greater than the fraction set point.

The invention is particularly adaptable to use in conjunction with paper-making processes. In particular, signal indicative of the moisture and weight of a finished paper product, derived from gauges at the dry end of the process, are utilized for deriving indications of the product fraction defective as regards moisture content and basis weight. The fraction defective moisture and basis weight signals are compared with target fraction defective values to derive error signals utilized in conjunction with other signals for controlling fibre flow and drying.

The above and other features will be apparent in the following detailed description of one specific embodiment of the invention, given by way of example and with reference to the accompanying drawings, wherein:

Figure 1 is a diagram schematically illustrating a preferred embodiment of the present invention, in combination with a paper making facility;

Figure 2 is a plot indicating possible statistical distribution of a product;

Figure 3 is a block diagram of one of the measuring circuits employed in the system of Figure 1;

Figure 4 is a circuit diagram of a fraction defective computer in the system of Figure 1;

Figure 5 is a block diagram of the fiber controller in the system of Figure 1; and

Figure 6 is a block diagram of the moisture controller in the system of Figure 1.

Reference is now made to Figure 1 of the drawings wherein there is illustrated a control system in accordance with the present invention, applied to a paper making facility. The paper making facility is of the conventional type, including a source 11 of clear water mixed with fiber from a source 12 in pipe 13. The fiber-water mixture in pipe 13 is fed through valves and controllers, described *infra,* to pump 14. Pump 14 also receives returned white water and feeds the white water and fiber-water mixture in pipe 13 to headbox 15.

Downstream of headbox 15, that includes the usual slice screws 16, is Fourdrinier wire 17. Water in the mixture emerging from the slice opening of headbox 15 is removed to a certain extent by suction and gravity through Fourdrinier wire 17, the drainage of which comprises the white water supply for pump 14. Downstream of Fourdrinier wire 17 are water removing press rollers 18, followed by drying section 19 which is controlled by the disclosed system as described *infra.*

Dryers 19 are divided into two sections; firstly, steam dryers 21, which are heated by steam emerging from supply 22 coupled to the dryers via valve 23 and manifold 24. Steam dryers 21 have a relatively long response time or time constant, of the order of one to two minutes as typical values, whereby one or two minutes is required for the temperature change of the dryers to reach approximately 63% of the temperature change called for by a controller. Dryers 19 also include a relatively high speed, segmented trim dryer 25. Dryer 25 is preferably positioned downstream of all of the steam dryers 21 as shown but differs from the steam dryers by having a fast response time, of the order of five seconds. Dryer 25 is divided into a plurality of separate, controlled sections disposed in a row across the width of the paper sheet. As is known in the art, such a segmented trim dryer may comprise a plurality of separate electric or gas dryers or a segmented air dryer.

The relatively moisture-free paper emerging from dryer section 19 is polished and smoothed by calender rollers 26. The sheet emerging from rollers 26 is the fuished product that is fed to a takeup roller, not shown.

The disclosed system, in addition to controlling the moisture removed by dryer section 19, enables the fiber weight per unit area of the paper to be controlled both along the sheet length and across the sheet width. To control the fiber along the sheet length, the ratio of clear water to fiber, that is consistency, of the mixture fed into headbox 15 may be controlled by valve 35 in the clear water line. The rate at which the fiber-water mixture is applied to pump 14 and headbox 15 is also controlled by valve 36, placed in series with line 13 upstream of pump 14. The relative weight per unit area of the paper can be controlled as a cross direction function by adjusting slice screws 16 relative to each other. In addition to being controlled by valves 35 and 36, slice screws 16 and dryers 19, the paper product can be varied in properties by changing the pressures between various pairs of the rollers 18.

Consideration is now given to apparatus utilized for deriving signals for driving the various controllers of fiber flow and drying rate. Determinations of the basis weight, i.e. total sheet weight per unit area, and per-cent moisture content of the sheet are derived with gauges capable of scanning the sheet at two separate locations in the process. Between press rollers 18 and steam dryers 21, at the wet end of the drying section, is positioned basis weight gauge 31; while downstream of calender rollers 26, at the dry end of the process, are located basis weight gauge 32 and

moisture gauge 33. Basis weight gauges 31 and 32 are preferably of the nucleonic type, including a penetrating radiation source and radiation detector, while moisture gauge 33 is preferably of the capacitance type. Gauges 32 and 33 are both mounted on the same traversing bracket, whereby the moisture and basis weight signals generated thereby provide measurements of virtually identical sections of the sheet.

Typically, the sheet being manufactured by the mill illustrated propagates at a velocity of the order of 700 to 1,000 feet per minute, whereby the transport lag in feeding the mixture, from pipe 13 to basis weight gauge 31 is of the order of 15 seconds, while the transport lag between gauge 31 and gauge 32 is approximately 1 minute.

In operation, gauges 31—33 are scanned across the width of the paper sheet to derive profile measurements indicative of wet end basis weight, dry end basis weight and moisture. The wet and dry end gauges are selectively scanned across the sheet width in response to an output of programmer 41. Gauges 31—33 are also selectively driven to a predetermined point across the width of the sheet to derive single point measurements of moisture and basis weight.

The responses of each of gauges 31—33 are respectively derived from measuring circuits 42—44, described *infra*, and may be considered as two separate data sets. While the gauges 31—33 are in a scanning mode, measuring circuits 42—44 generate varying D.C. voltages indicative of the instantaneous values of moisture and basis weight detected by the gauges. After a scan of gauges 31—33 has been completed, each of the corresponding measuring circuits 42—44 computes the average value for the previous scan of the property detected by the respective gauge. The average value is compared with the property value at the single point to establish the difference between the single point property value and the average property value over the scan. The difference between the single point and average value of the property is combined with the value of the property detected by the gauge during the following single point interval. Thereby, relatively accurate indications of the average value of the property are derived while the gauge is in a single point mode.

Programmer 41 controls gauges 31—33 so that the dry end gauges 32 and 33 are scanned approximately 95% of the time during system operation while gauge 31 is scanned only 10% of the time. Typically, two minutes are required for each scan of gauges 31—33; gauges 32 and 33 are in single point operation for one minute out of every twenty minutes; gauge 31 is scanned once during every twenty minutes; and during the first minute gauge 31 is being scanned gauges 32 and 33 are in the single point mode. It is to be understood that the times stated may be varied and do not include gauge standardization intervals.

In response to the normal operation conditions of the gauges, dry end gauges 32 and 33 drive circuits 43 and 44 so that the circuit outputs are representative of relatively long term, low frequency data indicative of the average properties of the sheet over a number of gauge scans at a plurality of points or the average value of each property being monitored across the sheet width scanned.

Scanning of gauges 32 and 33 is periodically terminated and they are activated to be single point mode to enable a relatively constant control action of the process to be computed for the same cross machine and machine direction region of the sheet as was monitored by gauge 31 at a time while it was in the single point mode. To this end, gauges 32 and 33 are driven by programmer 41 to a predetermined point across the width of the sheet for approximately one minute out of every 20 minutes. The single point position of gauges 32 and 33 is the same distance from the sheet edge as the single point position of gauge 31 and begins one minute after gauge 31 was removed from the single point condition and began scanning. Since there is a one minute transport lag between wet end gauges 31 and dry end gauges 32 and 33, the single point mode dry end gauges are responsive to about the same portion of the sheet as was monitored by gauge 31 during the last minute of its single point operation prior to the scan. The signals generated by circuits 43 and 44 for the one minute while dry end gauges 32 and 33 are in the single point mode can be made to coincide in time with the signal from the circuit 42 for the same portion of the sheet by delaying the wet end basis weight signal derived from measuring circuit 42. By combining the delayed signal from the wet end with signals derived from the dry end during the single point mode, the relatively constant wet end fiber fraction introduced by the Fourdrinier 17 and presses 18 is thereby determined periodically. In particular, the wet end fiber fraction, k, is determined by computing the sheet fiber content (BDBW), frequently referred to as bone dry basis weight, from single point outputs of dry end gauges 32 and 33, and taking the ratio of the fiber content to the wet end basis weight.

To derive the wet end fiber fraction signal, the wet end basis weight (WEBW) output signal of measuring circuit 42 is applied continuously to D.C. analog integrating network 46 which drives one minute delay network 45. Integrating network 46 has a time constant selected whereby the output voltage derived thereby is indicative of the signal applied thereto for the preceding minute. Thereby, for the minute while dry end gauges

32 and 33 are in the single point mode, the output of delay unit 45 is indicative of the average wet end basis weight of the portion of the sheet being monitored by gauges 32 and 33.

To compute the sheet fiber content at the dry end, the D.C. analog output voltages of measuring circuits 43 and 44 are selectively applied to the inputs of analog multiplier 47 and subtractor 48, respectively. The output signals of circuits 43 and 44 are fed to multiplier 47 and subtractor 48 through the normally open-circuited contacts of switches 51 and 52, which contacts are closed in response to the output of programmer 41 only during the one minute while dry end gauges 32 and 33 are in single point operation. Subtraction circuit 48 receives a constant D.C. voltage having a value representative of unity, as well as the output of moisture measuring circuit 44. Since the output of moisture measuring circuit 44 is proportional to the moisture content fraction by weight, of the sheet at the dry end of the process, subtracter 48 derives a D.C. voltage proportional to fiber percentage, by weight, in the sheet at the dry end. The percent fiber indicating output signal of subtracter 48 is multiplied by the dry end basis weight signal derived from measuring circuit 43 in multiplier 47, which therefore has a D.C. output voltage proportional to weight per unit area of fiber at the dry end (BDBW), a term frequently referred to in the art as bone dry basis weight.

The bone dry basis weight output voltage of multiplier 47 is applied to D.C. analog integrator 53, having a time constant equal to one minute, whereby the integrator derives a D.C. output voltage proportional to the average bone dry basis weight of the sheet at the dry end for the one minute while the gauges were activated to the single point mode. Thereby, upon completion of the one minute period of gauges 32 and 33 activated to the single point mode, the output voltages of delay unit 45 and integrator 50 are D.C. voltages respectively representing the average wet and basis weight ($\overline{\text{WEBW}}$) and average bone dry basis weight ($\overline{\text{BDBW}}$) for the same portion of the sheet. To compute the amount of moisture being removed from the sheet by dryer section 19 while the dry end gauges 32 and 33 were in the single point mode, these two output voltages are continuously applied as divisor and dividend inputs respectively to analog division circuit 54. Division circuit 54 responds to the two D.C. analog signals applied thereto to derive a D.C. analog output voltage representing a relatively stable-adaptive proportionality constant, k, indicative of the fraction of the basis weight at the wet end which is made up of fiber. The proportionality constant is therefore computed as:

$$k = \frac{(\overline{\text{BDBW}})}{(\overline{\text{WEBW}})} \qquad (1).$$

At the termination of the one minute period of gauges 32 and 33 being in the single point mode, the output voltage of divider 54 is gated through the normally open circuit contacts of switch 55 to analog memory 56. The contacts of switch 55 are closed for a relatively short time interval in response to a control signal from programmer 41 as each one minute single point mode operation of gauges 32 and 33 is being completed to load memory 56 with a new value of k, which is independent of any prior k value which may have been stored in the memory. Initially, memory 56 is preloaded with a value of k based on *a priori* knowledge of the paper machine characteristics.

Once a k value is stored in memory 56 it is available to be continuously read from the memory into apparatus for computing wet end moisture (M_w) and predicted bone dry basis weight ($\hat{BD}$) in response to basis weight signals derived from wet end basis weight gauge 31. The k value stored in memory 56 is utilized effectively to enable the fiber content or bone dry basis weight of the sheet portion passing wet end gauge 31 to be derived because the amount of moisture which dryer section 19 removes from the sheet remains relatively constant over a twenty minute period between calculations of k. The derivation of fiber content signals from the wet end gauge 31 output enables fiber flow control to be effected after approximately a 15 second transport lag.

The value of k stored in memory 56 is combined with the instantaneous wet end basis weight (WEBW) signal derived from gauge 31 and measuring circuit 42 to compute predicted dry end bone dry basis weight and wet end moisture weight per unit area as:

$$\hat{BD} = (\text{WEBW})k \qquad (2).$$

and

$$M_w = \text{WEBW}(1-k) \qquad (3).$$

From Equations (2) and (3) it can be appreciated how the value of k is used as a proportionality constant for determining predicted bone dry and wet end moisture weight per unit area. Since the value of k is computed in response to actual measurements made on the process and is not established on an *a priori* basis once the process has been in operation, the system can be considered as adaptive and k as an adaptive function.

To determine the values of $\hat{BD}$ and M_w, the D.C. output voltage of memory 56 is combined with the D.C. wet end basis weight output voltage of measuring circuit 42 in a computer comprising analog multipliers 57 and 58, as well as analog subtraction network 59. Multiplication network 57 responds to the output voltages of memory 56 and measuring circuit 42 to derive a D.C. voltage proportional to the value of predicted bone dry basis weight, as determined by Equation (2). The solution of Equation (3) involves feeding the output of memory 56 to subtraction network 59, the subtrahend input of which is a constant D.C. voltage representing unity. Thereby, subtraction network 59 derives a D.C. analog output voltage indicative of the percent moisture in the sheet at the wet end. The moisture indicating output voltage of subtracter 59 is multiplied by the basis weight output signal of measuring circuit 42 in multiplying network 58, giving a D.C. analog output voltage proportional to the total wet end moisture detected by gauge 31.

The predicted bone dry and wet end moisture signals respectively derived from multipliers 57 and 58 are utilized in a manner described *infra* for respectively controlling the flow of fiber into pump 14 and the amount of moisture removed from the sheet by dryer 19. Because sheet fiber content is calculated in response to measurements made at a relatively early or upstream portion of the process, fiber flow control can be made continuously or on a periodic basis of once every 15 seconds, the transport lag between the fiber-water inlet to pump 14 and wet end gauge 31. In contrast, fiber measurements made excessively from dry end gauges 32 and 33 make possible fiber flow adjustments approximately every 1.5 minutes. The calculation of wet end moisture enables dryer section 19 to be controlled to anticipate changes in the moisture of the sheet being fed to the dryer. Before considering the manner by which the output signals of multipliers 57 and 58 control the fiber flow to pump 14 and headbox 15, as well as the desorption rate of dryers 19, a description will be given of the method and apparatus for deriving other control parameters affecting fiber flow and moisture.

In addition to control by the outputs of multipliers 57 and 58, the fiber flowing into pump 14 and the desorbing properties of dryer 19 are responsive to signals representing amount of unacceptable product in the sheet passing dry end gauges 32 and 33. In the manufacture of paper, as all other products, the finished product has varying qualities which can be determined on a statistical basis. In paper manufacture, the quality of the product is determined by, interalia, the grade of fiber introduced into the process from source 12, the conditions of headbox 15, Fourdrinier wire 17, and the felts on rollers 18. If the process produces a product having properties conforming with a normal statistical distribution, a curve of the values of a property versus the amount of the product having the stated property values has the familiar, bell-shaped normal distribution curve. The maximum point on the curve is identical with the average value of the product produced. If the process produces a product conforming with the normal distribution, the process can be controlled in response to a function related to standard deviation. In particular, if a limit is set on the amount a product property may fall outside of a certain standard deviation, the average value of the product produced by the process can be controlled. Such a system for controlling a process is disclosed in our patent specification No. 1,250,196.

One problem, however, with the system disclosed in the aforesaid application is that the statistical computations become rather complex when the product does not follow a normal distribution. In paper manufacture, moisture and basis weight value commonly do not have a normal distribution. In the system disclosed herein, the quality of the paper product is determined by measuring the fraction or percentage defective of the sheet having amounts of moisture or fibre weight exceeding limits at the process dry end.

To explain the concept of fraction defective, reference is now made to Figure 2 of the drawings, wherein there is plotted, a graph of paper moisture distribution about an average. In particular, the abscissa in Figure 2 represents moisture content, while the ordinate represents amounts of the sheet having a particular moisture content. The distribution of moisture in the product illustrated by Figure 2 is not normal, as seen from the dips in the curve; it does follow general statistical laws since the ordinate values of the curve approach zero as the deviation from the mean moisture content, M, approaches infinity.

It can be determined that the product should be rejected or is unacceptable if the moisture thereof is more than a predetermined level, indicated on Figure 2 by the vertical line labelled "Reject Limit". For economy purposes, however, the paper maker is willing to accept the product even though it has a moisture content above the reject limit. The ratio of paper having a moisture content more than the reject limit to the total amount is referred to as fraction defective and is represented as the ratio of the area below the curve and to the right of the reject limit to the total area below the curve. Stated mathematically, moisture fraction defective, (MFD), is expressed as:

$$\mathrm{MFD}=\frac{\int_t^{t+T} f(M-M_R)dt}{\int_t^{t+T} 1dt} \quad (4)$$

where:

M is the instantaneous value of moisture detected by dry end gauge 33,

M_R is the moisture reject limit, indicated on Figure 2 and preselected by the paper manufacturer,

t is time,

T is an integration or averaging interval, generally equal to ten minutes,

$f(M-M_R)=0$ for M less than M_R; and

$f(M-M_R)=1$ for M equal to or greater than M_R.

To determine fraction defective of moisture in the finished paper product at the dry end of the process, the D.C. output voltage of measuring circuit 44 is continuously applied to fraction defective computing network 61, having analog computer circuitry described *infra* in conjunction with Figure 4. Fraction defective calculator 61 is also responsive to a D.C. input voltage, set by an operator, to represent the desired or set point moisture reject limit. Fraction defective computer 61 continuously derives a very slowly varying D.C. output voltage in accordance with Equation (4) and indicative of what percentage of the time the paper measured by gauge 33 has a moisture content greater than the limit M_R. Computer 61 is activated in response to the output of programmer 41 so that integrators therein are reset to a zero level periodically; a convenient resetting time being while gauges 32 and 33 are in the single point operating mode once every 20 minutes.

The output signal of computer 61 is fed to analog subtraction circuit 62, having a second input signal comprised of a D.C. voltage set by an operator to equal the percent or fraction defective the paper maker is willing to accept; typically the value set by the operator is about 3%. Thereby, subtraction circuit 62 derives continuously a very slowly varying D.C. error signal indicative of the deviation of the actual dry end fraction defective from the set point moisture fraction defective.

In accordance with the same theory as was developed for moisture fraction defective computation, computer 63 responds continuously to the output of basis weight and moisture measuring circuits 43 and 44 to derive indications of fraction defective fiber content. One difference between computers 61 and 63 is that the former determines fraction defective in response to moisture values above a reject limit, while the latter calculates fraction defective in response to fiber content signals less than a reject limit. It is also to be noted that for certain types of paper the calculation of moisture fraction defective is responsive to variations above and below moisture rejection limits.

The fiber content signal coupled to computer 63 is derived by feeding the moisture output signal of circuit 44 to an analog subtraction network 78, having a subtrahend input responsive to a constant D.C. voltage proportional to unity. The D.C. difference output voltage of subtracter 78, proportional to fiber percentage, is applied to an input of multiplier 79, the other input of which is the D.C. dry end basis weight output voltage of circuit 43. Multiplier 79 generates a D.C. output voltage representing fiber weight of the finished paper product in response to the inputs thereto, which voltage is coupled to fraction defective computer 63. Computer 63 responds to the actual fiber weight signal applied thereto by multiplier 79, and an analog D.C. set point voltage indicative of the fiber weight reject limit, to derive a fraction defective output signal in the same manner indicated *supra* regarding computer 61. The D.C. output voltage of computer 63 is compared in subtracter 64 with a set point indicating D.C. voltage that represents the desired value of dry end fiber fraction defective, $BDBW_{FD}$.

Generally, however, a paper maker does not determine the quality of the finished product in terms of fiber content, i.e., bone dry basis weight, but determines the product quality as a function of dry end moisture and basis weight. To compute the bone dry limit, therefore, the operator feeds voltages from D.C. sources (not shown) representing dry end basis weight and moisture limits into a fiber content computer connected in the same manner as subtracter 78 and multiplier 79. The fraction defective of fiber content is the same as the fraction defective for dry end basis weight because fraction defective is a ratio of acceptable product to total product and as such is not changed by equal variations of multiplying terms in the numerator and denominator. Thereby, the $BDBW_{FD}$ input signal to subtracter 64 can be merely relabelled BW_{FD}, basis weight fraction defective desired. The error is insignificant for normal moisture content.

The error signals generated by subtraction networks 64 and 62 are integrated by integrators 264 and 262 respectively, and respectively combined in computer 82 and controller 66 with the output voltages of multipliers 57 and 58 to control the flow of fiber into pump 14 and headbox 15 and the drying rate of dryer section 19 in a manner tending to reduce the error signals to zero.

The manner by which the output signals of multiplier 58 and integrator 262 are com-

bined in controller 66 for activating dryer section 19 will now be considered. Broadly, controller 66 derives a signal representing the total amount of moisture to be withdrawn from the sheet by the dryer sections 21 and 25 and controls the sections so that the relatively slow response time of steam dryers 21 is compensated by the segmented trim dryer 25, having a relatively fast speed of response. To allow for the transport lag between wet end gauge 31 and high speed trim dryer 25, there is a delay between the time a wet end moisture signal is derived from gauge 31 and the application of that signal to the trim dryer. In contrast, the wet end moisture signal derived from gauge 31 is applied immediately to slow response steam dryers 21. To maintain the total drying rate of dryer section 19 at a level determined by the output voltages of multiplier 58 and integrator 262 and independent of the divergent dryer response times, a feedback loop between the dryer sections is provided.

As described in detail *infra* in conjunction with Figure 6, controller 66 responds to the wet end moisture indicating output of multiplier 58 to derive a signal that is immediately coupled as a D.C. set point input voltage for a servo loop controlling steam dryers 21. The servo loop is also responsive to a D.C. voltage proportional to the actual drying rate of steam dryers 21 derived in response to signals from temperature transducers 68 and 69, mounted on each of the cylinders comprising the steam dryer. For purposes of simplicity, only the transducers 68 and 69 for two of the steam drying cylinders are illustrated. The signals from all of the temperature transducers are fed to computer 71, which generates a signal representing average temperature for the cylinders comprising steam dryer 21. The average temperature signal is utilized by computer 71 to derive a D.C. output voltage indicative of actual drying rate in steam dryer 21. The output of computer 71 is coupled to the servo loop in controller 66 and compared with the steam dryer set input derived in the controller to drive controller 72 for valve 23 in the steam supply line. Controller 72 is preferably of the integral type described in United States Patent No. 2,955,206.

High speed, fast response time trim dryer 25 is driven in response to the inputs to controller 66 in an entirely different manner from that utilized for driving steam dryer 21. In particular, controller 66 drives dryer 25 in response to a signal indicative of the desired drying rate of dryer 19, which signal is generated by combining the slowly varying moisture fraction defective error signal derived from integrator 262 with a delayed replica of the wet end moisture indicating output signal of multiplier 58. The wet end moisture signal is delayed by the transport lag between gauge 31 and trim dryer 25 because of the trim dryer high speed of response. To compensate for the response time properties of steam dryer 21, trim dryer 25 is also driven in response to the output of computer 71, indicative of the actual drying rate of steam dryer 21. The signals indicative of desired total drying rate and the actual drying rate of dryer 21 are combined in a second servo loop with the D.C. output of temperature transducer 65. Transducer 65 is mounted in trim dryer 25 so that the signal it generates is proportional to the actual trim dryer rate. Thereby, the error signal of the second servo loop is a D.C. signal indicating the drying rate set point for trim dryer 25 to satisfy the indicated drying rate for the entire dryer section 19. The error signal of the second servo loop is derived by controller 66 on lead 70 and is fed in a like manner to each segment of trim dryer 25 via adding networks 77 and dryer controllers 73, described *infra*. As time progresses and the actual drying rate of steam dryer 21 changes to catch up with the variations in detected wet end moisture, the error signal driving controllers 73 decreases, accompanied by a return of the trim dryer drive signal on lead 70 to approximately the same value as prior to a detected moisture change derived from multiplier 58.

According to another feature of the disclosed system, variations of wet end moisture for different points across the width of the sheet, i.e., at different cross machine direction locations, are compensated by deriving a composite moisture profile in response to the output of dry end scanning moisture gauge 33. The composite moisture profile is representative of the average moisture at different cross machine direction points over a relatively large number of scans of moisture gauge 33; typically the number of scans is selected as ten. To compute signals indicative of composite moisture profile, the output of measuring circuit 44 is applied to computer 75, which preferably takes a form described and illustrated in our patent specification No. 1,254,432. Composite moisture profile computer 75 is activated during the 95% of the time moisture gauge 33 is in the scanning mode, but is deactivated by programmer 41 while gauge 33 is in the single point mode. Moisture profile computer 75 is decoupled from gauge 33 while the gauge is in the single point mode because no profile data are being derived from the gauge at such times. Moisture profile computer 75 includes a plurality of outputs, equal in number to the number of segments in trim dryer 25, whereby it derives voltages indicative of the average moisture at a plurality of cross direction regions in response to several gauge scans at different machine direction locations. The output signals of composite moisture computer 75 are applied to profile levelling computer

76, having a number of outputs equal to the quantity of trim dryer sections. Computer 76 compares the separate profile signals to derive control voltages on its output leads whereby each of the trim dryer sections is adjusted so that the sheet has a consistent moisture across its entire width. Profile levelling computer 76 is described in either of United States patents Nos. 3,040,807 or 3,214,845.

Each of the outputs of profile levelling computer 76 is added in a like manner with the trim dryer output signal of controller 66 in the bank of adding circuits 77, equal in number to the number of segments of trim dryer 25. The analog output signals from each of the adders in bank 77 is applied to a separate one of the controllers in bank 73, which controllers generate power in accordance with the required heat in each of the sections of trim dryer 25. Thus, trim dryer 25 serves a dual function of levelling profile variations in the moisture content of the sheet and compensating for the lag of slow response steam dryers 21.

According to another aspect of the present system, the fiber content in the cross machine direction is adjusted so that it is relatively consistent. To this end, a composite fiber profile is derived from dry end gauges 32 and 33 to control the positions of screws 16 comprising the slice of headbox 15. The fiber content at the dry end of the process is calculated on an instantaneous basis in response to the outputs of dry end basis weight measuring circuit 43 and moisture measuring circuit 44 by subtraction network 78 and multiplier 79, as indicated *supra*. The output signal of multiplier 79 is fed to composite fiber profile controller 81, actuated in response to the output of programmer 41 at all times except when gauges 32 and 33 are in the single point mode. Controller 81 responds to successive scans of gauges 32 and 33 to derive a plurality of output signals, equal in number to the number of slice screws 16. The output signals of controller 81 are voltages indicating the amount by which a particular slice screw 16 must be adjusted to achieve uniformity of fiber content across the width of the sheet. The apparatus comprising controller 81 is similar to that described *supra* with regard to composite moisture profile computer 75 and profile levelling computer 76. The several output signals of controller 81 are applied to separate motors (not shown) for driving slice screws 16.

In addition to the cross direction fiber control performed by controller 81 on slice screws 16, the present system provides means for controlling the fiber flow into headbox 15, whereby the total fiber in the sheet, along its length or in the machine direction, is maintained within bounds. A set point signal for the amount of fiber flow into pump 14 and headbox 15 is derived in response to the relatively high frequency predicted bone dry or fiber content output signal of multiplier 57 and the slowly varying fiber content error fraction defective output signal of integrator 264. Because fiber flow control is in response to the fiber content signal derived from measurements made at the wet end of the process, at a position comparatively close to the fiber flow inlet, relatively continues control of fiber flow can be attained.

The output signals of multiplier 57 and integrator 264 are combined to derive a fiber flow set point in fiber flow computer 82. Fiber flow computer 82 derives a fiber flow set point output by subtracting a predetermined D.C. voltage representing a predetermined value of fiber content based on *a priori* knowledge from the predicted fiber content signal generated by multiplier 57. The resulting error signal between the predicted and predetermined fiber content is multiplied by a constant and added with the fiber content fraction defective error output signal generated by integrator 264. Stated mathematically, the value of output signal, F, derived by computer 82 is expressed as:

$$F = -Q(\hat{BD} - \hat{BD}_o) + \int(BDBWFDE) \quad (6)$$

where:

$\hat{BD}$=predicted instantaneous bone dry output of multiplier 57,

$\hat{BD}_o$=predetermined fiber content,

Q=a constant, and

(BDBWFDE)=the error of fiber content fraction defective.

The fiber flow set point output voltage of computer 82 is integrated by integrator 282 and fed to fiber flow controller 84, described in detail *infra* in conjunction with Figure 4, which derives output signals to control the amount of fiber flowing into pump 14 from source 12 by adjusting valves 35 and 36. Fiber flow controller 84 responds to the output of fiber flow computer 82 so that with a predetermined setting of water flow valve 35, mixture valve 36 is adjusted until the maximum flow rate that the system can handle is attained. After the maximum flow rate that the system can handle is attained by opening valve 36 to its fullest extent, the ratio of fiber to clear water flowing into pipe 13 is changed from the preadjusted value by adjusting valve 35 to satisfy the set point output of flow computer 82.

Control of valves 35 and 36 in response to the consistency and flow indicating output voltages derived from fiber flow controller 84 is by means of conventional servo feedback loops. In particular, the consistency or percentage fiber of the material flowing in line

13 is measured with gauge 85, the output signal of which is a D.C. voltage that is compared with the consistency output signal of fiber flow controller 84 in subtraction network 86. The error signal derived from subtraction network 86 is fed to servo 87 that adjusts the setting of valve 35. The volume flow rate of material moving through the line through valve 36 is measured with flow meter 88, deriving a D.C. output signal which is compared in subtraction network 89 with the desired or set point for flow through valve 36. The error signal derived from subtraction network 89 is fed to servo actuator 91, whereby the set point flow rate output of controller 84 is maintained.

Consideration is now given to the apparatus and operating mode of measuring circuit 42 by referring to Figure 3. Broadly, measuring circuit 42 computes average basis weight for the entire sheet while gauge 31 is in the single point mode by initially calculating the profile average basis weight in response to gauge 31 scanning across the sheet width. The computed, average basis weight signal is compared with the basis weight at the cross machine direction point where gauge 31 is located during the single point mode, whereby an error between the selected point and average basis weight is established. The error voltage is combined with the basis weight gauge output signal while the gauge is in the single point mode to derive the indication of average basis weight on an instantaneous basis.

To these ends, the D.C. analog voltage generated by basis weight gauge 31 is coupled to three parallel channels, respectively including subtraction circuit 101, sample and hold circuit 102 and profile averaging computer 103. Profile averaging computer 103 is responsive to signals from programmer 41, whereby the averaging process is performed only while gauge 31 is being scanned across the width of the sheet. In contrast, sample and hold network 102 is responsive to the output of basis weight gauge 31 whenever the scanning gauge passes over the preselected point where the gauge is driven while it is in the single point mode. The output voltages of sample and hold network 102 and profile averaging computer 103 are supplied as input signals to analog computer subtracter 104. Hence, upon the completion of a scan of gauge 31 across the width of the sheet, the output voltage of subtracter 104 is a signal representing the difference in basis weight at the selected point from the average basis weight across the entire sheet.

The output voltage of difference network 104 is coupled through switch 105 to analog memory 106 upon the completion of a scan of gauge 31 in response to the switch being closed by the programmer at that time. Analog memory 106 stores the signal fed thereto through switch 105 until another signal is fed to the memory in response to the next closure of the contacts of switch 105. The output of analog memory 106 is continuously derived and normally fed through the contacts of normally closed switch 107 to an input of difference network 101, the other input signal of which receives the output of basis weight gauge 31. Switch 107 is normally maintained in the closed position in response to signals from programmer 41, except during the interval when gauge 31 is being scanned across the sheet. Thereby, at all times while basis weight gauge 31 is in the single point mode, the difference output signal of subtractor 101 is a D.C. analog voltage representing the average basis weight of the sheet as it passes wet end gauge 31.

To determine the average basis weight of the sheet while gauge 31 is scanning across the sheet, the value of the profile average during the preceding scan of the gauge is stored. The stored voltage is compared with the output of basis weight gauge 31 while the gauge is making a new scan, which occurs 20 minutes subsequent to the scan which resulted in the previously stored profile average signal. To derive the average sheet basis weight signal while gauge 31 is in the scanning mode, the output of profile average computer 103 is applied to analog memory 108 through switch 109 at the same time that the output of subtracter 104 is applied to analog memory 106. Memory 108 stores the profile average output of computer 103 until the contacts, of normally open switch 109 are again closed by the output of programmer 41. The output of analog memory 108 is coupled through switch 111 to one input of subtraction circuit 112 during the entire time while gauge 31 is scanning across the sheet in response to a control signal applied to the switch by programmer 41. During the interval while gauge 31 is scanning across the width of the sheet, programmer 41 activates switch 107 so that the output voltage of memory 106 is decoupled from the difference circuit 101. Thereby, the second input to difference network 112 is responsive solely to the output voltage of basis weight gauge 31 and the output voltage of network 112 is a D.C. analog voltage proportional to the instantaneous basis weight of gauge 31 while it is in the scanning mode minus the profile average basis weight taken for the previous scan of gauge 31.

While basis weight gauge 31 is in the single point mode the input from switch 111 to subtraction network 112 is zero because switch 111 is maintained in an open circuit condition in response to the output of programmer 41. Hence, the average basis weight difference signal derived from subtraction network 101 is coupled directly through difference network 112.

It is to be recognized that the circuit of Figure 3 can also be employed, with slight

modification, for each of measuring circuits 43 and 44. It is to be recalled that dry end gauges 32 and 33 scan across the width of the sheet continuously, except for a one minute time interval while they are in the single point mode. Gauges 32 and 33 are positioned, while in the single point mode, at the same location across the sheet width as wet end gauge 31 while it is in the single point mode. Dry end gauges 32 and 33 are in the single point mode during the first minute while wet end gauge 31 is being scanned, whereby the same cross and machine direction region of the sheet is monitored by all of gauges 31—33. To enable a comparison of the data derived from gauges 32 and 33 while they are in the single point mode to be made with the corresponding data derived from the sheet while gauge 31 is in the last minute of single point operation prior to scanning, each of measuring circuits 43 and 44 subtracts from the instantaneous output of the gauge to which it is responsive the deviation of the single point measurement from the profile average derived from the previous scan of the gauges.

To these ends, Figure 3 is modified so that networks 101—103 are responsive to the output signals of detectors 32 or 33, depending upon whether circuit 43 or 44 is being considered. For purposes of simplicity in explanation, basis weight gauge 31 of Figure 3 is assumed to be replaced with basis weight gauge 32 in considering the manner by which measuring circuit 43 functions. It is to be understood that measuring circuit 44 responds to moisture gauge 33 in exactly the same manner as to be described for measuring circuit 43.

While the basis weight gauge 32 at the dry end is scanning profile averaging computer 103 is activated by programmer 41; at the same time programmer 41 open circuits each of switches 105, 107, 109 and 111. Thereby, the output signal of subtraction network 112 is a measure of the instantaneous basis weight sensed by scanning gauge 32, which signal is coupled to basis weight fraction defective computer 63, as well as to composite fiber profile controller 81, via multiplier 79. Upon the completion of each scan of basis weight gauge 32, the output voltage of profile average computer 103 is a measure of the average basis weight across the sheet width. The signal accumulated by computer 103 during each scan is normally read from the average computer upon the completion of each scan in response to a signal from programmer 41, which simultaneously discharges capacitors in the averaging network to zero. The output of averaging computer 103, however, is normally decoupled from any of the other circuits in the network since all of switches 105, 107, 109 and 111 are open circuited by a control signal from programmer 41.

Upon completion of the scan immediately preceding operation of gauge 32 in the single point mode, programmer 41 derives a control signal to close switches 105 and 107. A microswitch is provided to enable sample and hold network 102 in response to each passage of gauge 32 over the single point location. Upon the completion of each scan of gauge 32 there is thereby derived from subtracter 104 a voltage proportional to the difference in the average and single point basis weights. The subtracter 104 D.C. analog output voltage is coupled to memory 106 only in response to switch 105 being closed by programmer 41 once every 20 minutes, immediately prior to gauge 32 being driven to the single point mode. With the closure of switch contacts 105 analog memory 106 is thereby reloaded once every 20 minutes with a signal indicative of the departure in dry end basis weight at the single point location from the average basis weight across the sheet.

The output of memory 106 is coupled to one input of subtraction circuit 101 during the entire one minute interval while gauge 32 is in the single point mode in response to the contacts of switch 107 being closed during said time by programmer 41. Thereby, the output voltage of subtracter 101 is indicative of profile average basis weight of the sheet for each instant during a one minute interval while gauge 32 is in the single point mode. The output of subtracter 101 is fed through subtracter 112 in unmodified form, since the other subtracter input signal from switch 111 is zero, and coupled through switch 51 as indicated *supra* to enable the adaptive constant k to be recomputed once every 20 minutes.

Reference is now made to Figure 4 of the drawings wherein is illustrated a schematic diagram of an analog computer version of the fraction defective computer. The fraction defective computer of Figure 4 may be utilized, with slight modification, either as computer 61 or 63 to determine the fraction defective of dry end moisture or fiber content, respectively. It is to be recalled from the discussion of Figure 2 and Equation (4) that fraction defective is the ratio of the amount of paper for which the monitored variable is less than or greater than a limit value of the variable divided by the total amount of paper being manufactured, a ratio of two areas or integrals.

From Equation (4), the integral comprising the numerator of the ratio is the total time the amount of material is greater or less than a limit; determined with the circuit of Figure 4 by upper channel 121. Channel 121 includes diode 122 connected in series between input terminals 120, D.C. voltage source 123 and relay winding 127 which is energized whenever the normally back-biased path through the diode and D.C. source is rendered into a low impedance state. Energiza-

tion of relay 127 results in normally open-circuited contact 128 being closed to couple a reference voltage from source 129 to the input of D.C. analog integrator 124, which is reset by programmer 41 once every 20 minutes. The potential, M_R, of D.C. source 123 is variably controlled by the paper maker to correspond with the acceptable limit or boundary of moisture or basis weight, as indicated by the reject limit line of Figure 2.

D.C. source 123, in combination with diode 122, establishes the reject limit because the combination respectively represents open and short circuit conditions for voltages at terminals 120 greater and less than M_R. In response to the circuit comprising diode 122 and source 123 being respectively activated to the short and open circuit conditions, the reference voltage of source 129 is fed directly to integrator 124 or the integrator 124 input is zero. Integrator responds to the zero or predetermined finite voltage fed thereto to derive an output having an amplitude indicative of the dividend of Equation (4), *supra.*

The output voltage of integrator 124 is divided by a signal indicative of the total time upper channel 121 has been activated since the last reset of integrator 124, i.e., the activation time of the process or defective computer. The activation time signal is derived by feeding a constant D.C. voltage from source 130 to the input terminals of integrator 125, which is reset simultaneously with integrator 124. Thereby, the output of integrator 125 is a sawtooth voltage increasing in amplitude linearly as a function of time relative to the last reset of integrators 124 and 125. Division of the output of integrator 124 is performed in analog division network 126. Division network 126 includes dividend and divisor inputs respectively responsive to the D.C. output voltages of integrators 124 and 125. Thereby, the output voltage of division network 126 is a D.C. signal having an amplitude equal to the ratio of the amount of defective product, i.e., the amount of product having a value outside the limit M_R, to the total amount of the product. As indicated *supra*, the ratio output of division network 126 is, therefore, indicative of the precentage of the sheet having defective moisture or basis weight, referred to herein as fraction defective.

Reference is now made to Figure 5 of the drawings wherein there is illustrated a schematic diagram of the apparatus comprising fiber flow controller 84. Broadly, it is the function of controller 84 to adjust valves 35 and 36 so that a fiber flow set point derived from integrator 282 is attained for the slurry fed to pump 14 and headbox 15.

Controller 84 responds to the set point output of integrator 282 and to consistency and flow rate transducers 85 and 88 in line 13 respectively upstream and downstream of valve 36 to derive a signal indicative of the amount of fiber flow change that should be made. The fiber flow change signal is combined with the actual flow signal derived from transducer 88 to establish a signal indicative of corrected fiber flow into pump 14. If the corrected fiber flow exceeds a limit established by the action of valve 36 on the total mass fiber mixture, consistency valve 35 for the clear water source 11 is activated. Otherwise, valve 35 is maintained at a preselected point and the consistency of the mixture flowing in pipe 13 is not changed.

To these ends, the circuit of Figure 5 includes multiplier 141 responsive to the consistency and flow rate output signals of transducers 85 and 88, respectively. The output signal of multiplier 141 is, therefore, a D.C. amplitude proportional to the actual fiber flow into pump 14 from pipe 13. The fiber flow output signal of multiplier 141 is compared in subtraction circuit 142 with the set point fiber flow derived from integrator 282. The output of difference circuit 142, indicative of the fiber flow error, is applied as a numerator input to division circuit 143, the dividend input of which is the D.C. output of consistency transducer 85.

In response to the inputs applied thereto, division circuit 143 derives a signal proportional in amplitude to the error or change to be effected between the actual flow and the desired flow, as reflected by the flow rate output of subtraction circuit 142. The change in the flow rate of the mixture in pipe 13 is combined with the actual flow rate derived from transducer 88 in analog computer summing network 144, the resultant output of which is applied to limit detector 145.

Limit detector 145 derives a binary one signal only in response to the output of adding circuit 144 exceeding or being equal to a predetermined limit, commensurate with the limit of flow which can be passed through valve 36. Whenever the output of adding circuit 144 indicates that the flow would be less than the limit that valve 36 is capable of passing, the output of limit detector 145 is a binary zero.

The binary output signal of limit detector 145 is applied as a control voltage to switch 146, whereby the switch armature 147 respectively engages contacts 148 and 149 in response to the binary zero and one outputs of limit detector 145. Switch 146 selectively gates the output voltage of adding circuit 144 to the servo loops for valves 35 and 36. With armature 147 engaging contact 148, the output voltage of adding circuit 144 is applied directly to one of the inputs of subtraction network 39 in the feedback loop controlling valve 36. In contrast, engagement of armature 147 and contact 149 results in the output voltage of adding circuit 144 being applied

to an input of subtraction network 86 in the servo loop for control of valve 35.

The signal applied to the servo loop controlling valve 36 can be applied directly, without modification, since the signal indicates flow rate set point. In contrast, the signal for controlling valve 35 must be altered to reflect a predetermined consistency control. To this end, terminal 149 is connected to the numerator input of division circuit 151, the divisor input of which is responsive to the flow indicating output of transducer 88. In response to a finite fiber flow change numerator signal being applied thereto through switch 146, division circuit 151 derives an output voltage indicative of one plus the ratio of the flow rate change calculated by division circuit 143 to the actual flow rate in pipe 13, as derived from transducer 88. The consistency output signal of division circuit 151 is combined in adder 152 with a predetermined D.C. voltage from source 153 and indicative of the predetermined consistency for the ratio of fiber to clear water from sources 12 and 11, respectively. The output of adder 152 is applied to an output of subtraction network 86 in the feedback loop controlling valve 35. Thereby, if the limit established by detector 145 is not exceeded by the output of adder 144, only the preset input to summing network 152 is constantly applied to the servo loop for valve 35. In the event the limit of detector 145 is exceeded, however, valve 36 is driven to its widest opening and valve 35 is controlled in response to the error indicating consistency signal derived from division circuit 151, as well as from the preset signal applied to adder 152.

Because the fiber set point input signal to controller 84 is derived primarily from wet end gauge 31, the dry end fraction defective signal being of very low frequency and not subject to short term variations, the fiber controller output signals can be applied continuously or approximately once every 15 seconds to the actuators of valves 35 and 36. In contrast, prior art techniques relying upon gauge readings at the dry end of the process limit the application of control signals to the valve actuators to a periodicity of the order of the total process transport lag, 1.5 minutes generally. Continuous or 15 second control can be effected with the present system because it is not necessary to wait a protracted time interval prior to determining what effect the previous control action had on the product.

Reference is now made to Figure 6 of the drawings wherein there is disclosed in block diagram form the apparatus comprising moisture computer 66. It is to be recalled that the function of moisture computer 66 is to determine the drying rate of steam dryer 21 and trim dryer 25. In general, the moisture computer responds to the wet end moisture indicating output signal of multiplier 58 and immediately applies a control signal to slow response time steam dryer 21. Simultaneously, the wet end moisture indicating output signal is delayed for a time commensurate with the transport lag between wet end gauge 31 and trim dryer 25 and is combined with the moisture fraction defective error output of integrator 262 to derive a signal indicative of the total drying rate requirement of both the steam and trim dryers in section 19. The total drying rate requirement signal is compared with error signals from the steam and trim dryers to control the trim dryer drying rate.

Referring to Figure 6 in particular, the wet end moisture output of multiplier 58 is fed through delay element 161, having a delay time equal to the transport lag between wet end gauge 31 and trim dryer 25, to computer 162 which derives an output signal indicative of the total drying rate requirement of dryer section 19. Computer 162 scales the delayed wet end moisture signal by a constant R_1 and linearly combines the resultant with the output integrator 262. Thereby, the D.C. output voltage, (V_{inst}) of computer 162 indicative of the set point for the drying rate of dryer 19 is represented as:

$$V_{inst} = R_1(M_w)_D + \int EFDM,$$

where:

R_1=constant,

$(M_w)_D$=wet end moisture delayed for the transport lag between gauge 31 and trim dryer 25, and

EFDM=fraction defective error in moisture.

The total drying rate requirement indicator output signal of computer 162 is compared in analog summing circuit 163 with the actual drying rate of steam dryer 21. Analog summing circuit 163 responds to the stated inputs thereof to derive a trim dryer set point voltage in accordance with:

$$V_t = V_{inst} - V_{sa}$$

where:

V_t=the set point for trim dryer 25,

V_{sa}=the actual drying rate of steam dryer 21, and

V_{inst}=the total drying rate requirement of both the steam and trim dryers, as derived by the output of computer 162.

Prior to considering the manner by which the signal V_{sa} is derived, consideration will be given to the control apparatus for steam dryers 21. Steam dryers 21 are responsive to the wet end moisture indication, M_w, derived from multiplier 58 immediately upon the derivation thereof. The wet end moisture indicating output of multiplier 58 is scaled by a

predetermined constant, R_2, in analog multiplication network 164, the output of which is a D.C. signal indicative of the required drying rate V_{mw} of dryer section 19. V_{mw} is also used to represent the set point drying rate for steam rollers 21. Because of the inherent lag of steam dryers 21, the set point output voltage of multiplier 164 is applied directly to the input of a servo system including analog difference network 67, the output of which drives integral controller 72 for valve 23 in the steam line.

Difference network 67 is also reponsive to the D.C. signal V_{sa} indicative of the actual drying rate of steam dryers 21. The signal representing actual drying rate of dryers 21 is derived from measurements of the actual average temperature in steam dryers 21, generated by temperature transducers 68 and 69, having outputs which are fed to computer 71. Computer 71 comprises a non-linear function generator of a known type which is empirically calibrated to relate the surface temperature of the dryer to the drying rates determined from experimental data. It responds to the average of D.C. voltages generated by the transducers as at 68 and 69 to derive a voltage that is fed to difference network 67 and is proportional to the actual drying rate of steam dryers 21.

The set point for driving all of the sections comprising trim dryer 25 is adjusted to enable the trim dryer to remove any moisture from the sheet that should have been, but was not, removed by steam dryer 21. The set point signal is thereby derived by subtracting in analog difference circuit 163 the output of computer 71 from the total drying rate requirement D.C. output signal of computer 162. The D.C. output of difference network 163 is compared in analog subtraction circuit 165 with the actual trim dryer drying rate signal generated by temperature transducer 65 mounted in the fast response time dryer. Difference circuit 165 derives an error signal for controlling all of sections of the trim dryer 25 alike, which error signal is coupled to dryer controllers 73 via adders 77, as indicated *supra*.

To provide a better understanding of the drying system operation, let it be initially assumed that the same wet end moisture and moisture fraction defective error signals have been derived from multiplier 58 and subtracter 62 for a relatively long time period. Under such circumstances, the conditions of steam dryer 21 and trim dryer 25 are stabilized and zero error signals are applied to controllers 72 and 73. Now let it be assumed that an unusually moist spot in the sheet is detected by wet end basis weight gauge 31, as reflected in the output signal of multiplier 58. At the same time, it is assumed that the slowly varying moisture fraction defective error remains constant.

Under the assumed conditions, the wet end moisture output signal of multiplier 58 is scaled in multiplier 164 and applied to error sensing subtraction circuit 67. Subtraction circuit 67 thereby derives an error signal indicative of the amount by which the steam applied by source 22 to dryers 21 should be increased. The error signal generated by circuit 67 is applied to controller 72 that drives valve 23 to open it to a greater extent and additional steam is supplied from source 22 to dryers 21. The dryers, however, do not respond instantly to steam from source 22, but have an exponential rise in drying capabilities with a time constant of the order of two minutes. While the drying rate of steam dryers 21 slowly increases, the output of computer 71 also increases and the error output of difference circuit 67 is decreased slightly.

During about the first minute after the wet spot had been detected by gauge 31, the increase in the drying rate occasioned by steam dryers 21 is compensated with a decrease in the drying rate of trim dryer 25 through control of trim dryer 25 servo loop by circuit 163. The trim dryer drying rate is decreased because of the transport lag between wet end gauge 31 and trim dryer 25 and occurs because the output voltage of computer 163 is decreased in response to the increasing value of the value of V_{sa} while the value of V_{Inst}, the output of computer 162, remains constant.

Upon completion of the transport lag between wet end gauge 31 and trim dryer 25, the wet end moisture change is reflected in the output of delay element 161 and is fed to computer 162. The computer responds immediately to the change in wet end moisture set point input fed thereto to derive a signal indicating that the total drying rate requirement of section 19 has increased. When the output of computer 162 suddenly increases, the actual drying rate of steam dryers 21 has increased to approximately 40% of the change derived about one minute earlier from the output of multiplier 58. The output voltage of computer 163 responds to the difference in the V_{sa} and V_{Inst} outputs of computers 71 and 162 to derive an indication that the other 60% of the desired drying rate of dryer 19 must be temporarily made up by trim dryer 25. The change in the set point of trim dryer 25 at this time is, however, equal to the sudden change in the output of computer 162 since the trim dryer output was previously reduced to compensate for the slow rise in the actual drying rate of steam dryers 21. As time progresses, the moisture actually removed by steam dryers 21 increases to a point whereby the error indicating output signal of difference network 67 is again zero. Under such circumstances, it is no longer necessary to compensate for the lag of the steam dryers and the output of computer 163 will have returned

to the same value as was derived therefrom prior to the change in the sheet condition discussed.

The analog computer apparatus disclosed herein can be replaced with a digital computer system having either a hard wire or soft ware program to control the sheet manufacture. In addition, activation of the various controllers may be effected manually in response to visual indications of the various control signals derived, instead of automatically.

Reference is directed to our co-pending patent applications Nos. 38414/71 and 38516/71, (Serial Nos. 1266222 and 1266223), in which the same specific embodiment is described and other aspects thereof are claimed.

WHAT WE CLAIM IS:—

1. A method of controlling a variable property of the product or output of a manufacturing process or step, wherein the fraction of the product being produced in respect of which the property value falls outside a selected reject limit value is determined and utilised to maintain said fraction substantially constant.

2. A method according to claim 1, wherein the actual fraction of the product in which the property value falls outside the selected reject limit is determined and compared with a preselected desired value of this fraction, and a parameter of the process is controlled so that the compared fractions are substantially equalized.

3. A method of controlling a variable property of the product or output of a manufacturing process or step, wherein the target or set point value for the property is changed in accordance with changes in the fraction of the total product being produced in respect of which the property value falls outside a selected reject limit value, the target value being shifted toward the reject limit when said fraction falls and shifted away from the reject limit when said fraction rises, in such manner as to tend to keep said fraction substantially constant.

4. A method according to claim 1, or claim 3, comprising the steps of monitoring variations of the property, computing from the monitored property variations and the selected reject limit value for the property the fraction of the product in which the property value is outside the reject limit, comparing this fraction of the product having a property value outside the reject limit with a preselected desired value for this fraction to derive an error signal quantity, and shifting the set point of a regulating device that regulates a process parameter controlling the property, said regulating device set point being shifted in a manner tending to cause reduction of the error signal quantity to zero magnitude regardless of the sign of the error signal.

5. A method according to claim 4, wherein said regulating device set point and the value of said process parameter are combined to derive a control signal which is employed in adjusting the regulating device to a new setting.

6. A system for controlling a variable property of the product or output of a manufacturing process or step, comprising means monitoring the value of the property for deriving a fraction defective signal indicative of the actual fraction of the product having a property value outside of a selected reject limit, means comparing said fraction defective signal with a signal indicative of a selected set point for the fraction for deriving an error signal, and means responsive to the error signal for controlling the magnitude of a target value for the property in such a manner that the target value for the property is varied to approach the reject limit in response to the actual fraction being less than the fraction set point and to recede from the limit in response to the actual fraction being grater than the fraction set point.

7. A system according to claim 6, wherein said fraction defective signal deriving means includes means for computing:

$$\frac{\int_{t_i}^{t_i+T} f(x-x_R)dt}{\int_{t_i}^{t_i+T} 1dt}$$

where:

x=the instantaneous value of the property,

t_i=the instant of time at which the integrating interval T begins

t is time

x_R=the reject limit,

$f(x-x_R)=0$ for x less than x_r

$f(x-x_R)=1$ for x equal to or greater than x_R.

8. A system according to claim 6 or claim 7, wherein said fraction defective signal-deriving means includes gauge means measuring the value of the property thereby to derive a first signal indicative of the property variations, and fraction defective computer means wherein said first signal is compared with a preset reject limit signal.

9. A system according to claim 6 or claim 7 or claim 8, further comprising a regulating device that regulates a process parameter controlling the property, and means responsive to said error signal for changing a set point signal for the regulating device so as to cause the regulating device to control the property in a manner tending to reduce the error signal to zero magnitude regardless of the error signal polarity.

10. A system according to claim 9, further

comprising means combining said regulating device set point signal and a signal indicating the value of said process parameter to derive a control signal for said regulating device.

11. A system according to claim 8 or claim 9 or claim 10, for controlling the drying rate of dryers in a paper-making mill, wherein the gauge means measures the quantity of moisture in the paper sheet downstream of the dryers, the reject limit is a moisture content reject limit and the fraction defective computer computes the fraction defective in regard to moisture content which is compared with a set point for moisture content fraction defective of the paper to derive the error signal, having one polarity when the computed moisture content fraction defective exceeds the set point and the opposite polarity when the computed moisture content fraction defective is less than the set point, the target value for sheet moisture being shifted in response to the error signal in a direction to reduce the error signal to zero regardless of the error signal polarity.

12. A system according to claims 10 and 11, wherein said regulating device regulates the sheet dryer drying rate, in accordance with a signal derived by means responsive to a gauge measurement signal indicative of dryer drying rate and the regulating device set point signal.

13. A system according to claim 12, including further gauge means for detecting the fibre content of the sheet, means responsive to the signal output of this further gauge means for deriving a signal representative of the product fraction in which the fibre content is beyond a selected reject limit, means for comparing this fibre content fraction defective signal with a selected set point for fibre content fraction defective to derive a second error signal, and a fibre flow regulating device having an operative set point which is shifted in response to said second error signal thereby to reduce said second error signal toward zero.

14. A system according to claim 8 or claim 9 or claim 10, for controlling the flow of fibres into a paper-making mill, wherein the gauge means measures the quantity of fibre in the sheet, the reject limit is a fibre content reject limit, and the fraction defective computer computes the fraction defective in regard to fibre content which is compared with a set point for fibre content fraction defective of the paper to derive the error signal, having one polarity when the computed fibre content fraction defective exceeds the set point and the opposite polarity when the computed fibre content fraction defective is less than the set point, the target value for sheet fibre content being shifted in response to the error signal in a direction tending to reduce the error signal to zero regardless of the error signal polarity.

15. A system according to claims 10 and 14, wherein said regulating device regulates the fibre flow rate, in accordance with a signal derived by means responsive to a signal indicative of actual fibre flow rate and the regulating device set point signal.

16. A system according to claim 14 or claim 15, further including gauge means responsive to the quantity of moisture in the processed sheet for deriving a signal representative of the moisture quantity, means responsive to this moisture quantity signal for deriving an indication of a statistical function of the paper quality from a comparison of moisture content and a signal representing a preset moisture content reject limit, and means for controlling the moisture content in response to sigal inputs representative of said statistical function indication and of a selected set point therefore.

17. A process control system for a paper-making mill, substantially as described with reference to the accompanying drawings.

For the Applicant:
LLOYD WISE, BOULY & HAIG,
Chartered Patent Agents,
Norman House,
105—109 Strand,
London, WC2R OAE.

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1266221 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

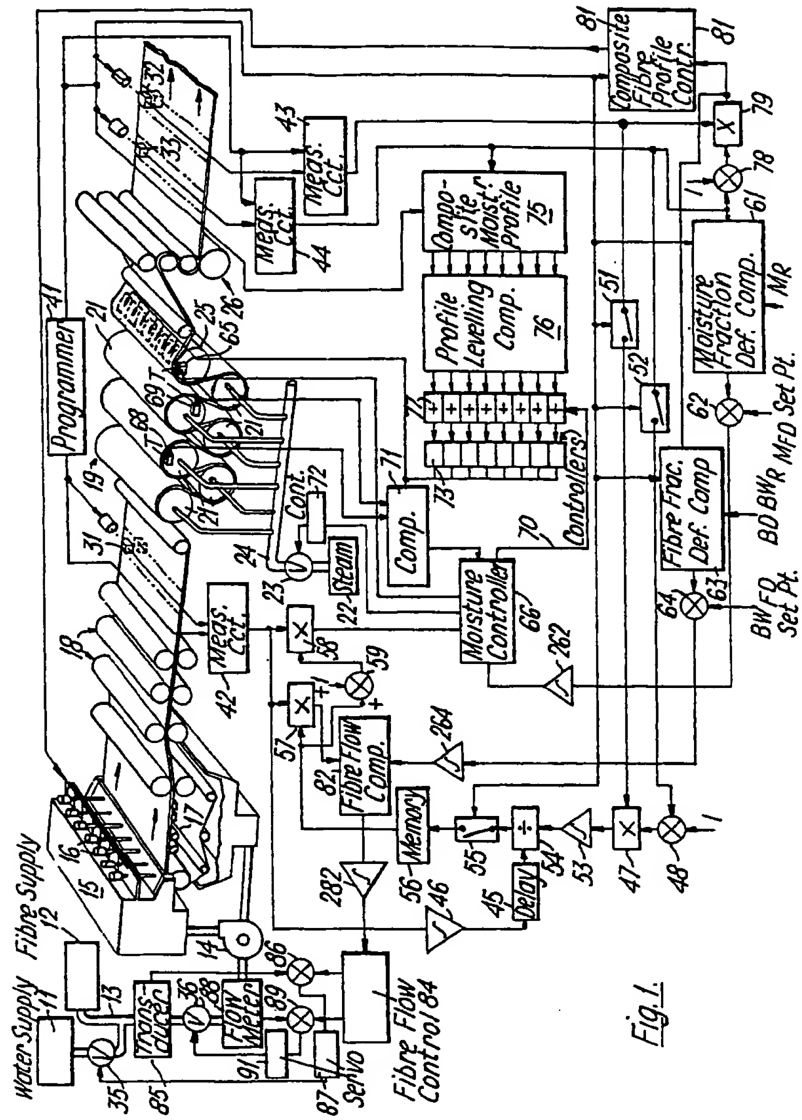

Fig.1.

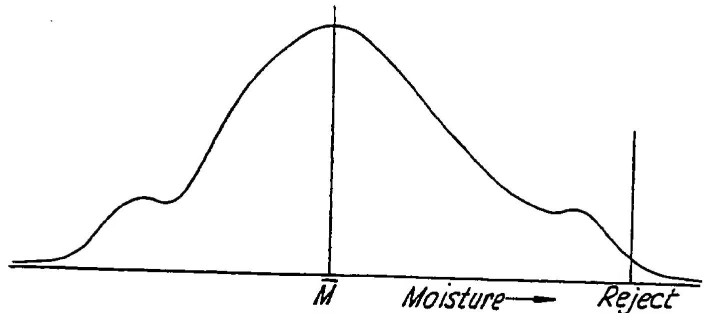

Fig. 2.

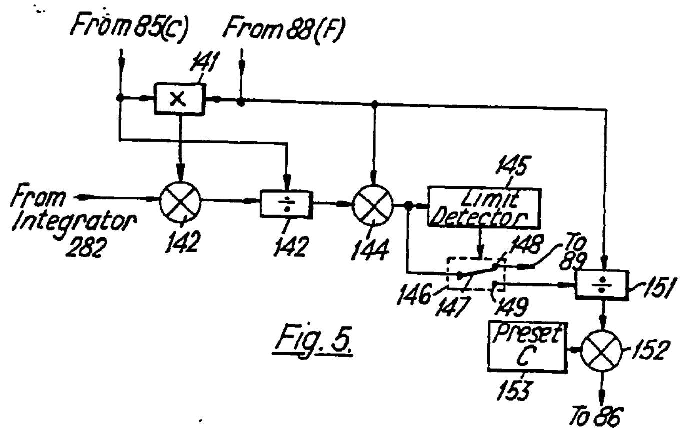

Fig. 5.

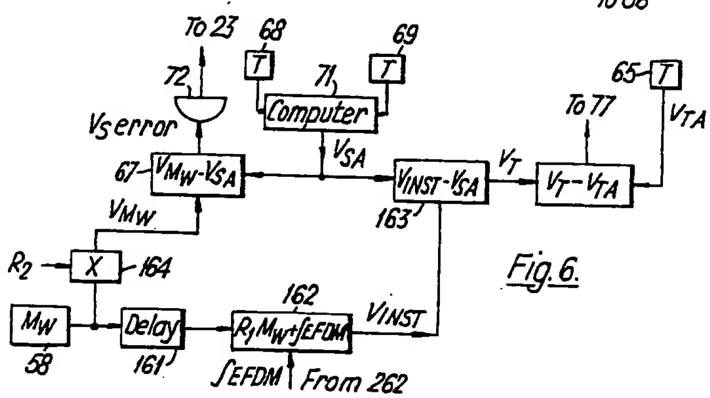

Fig. 6.

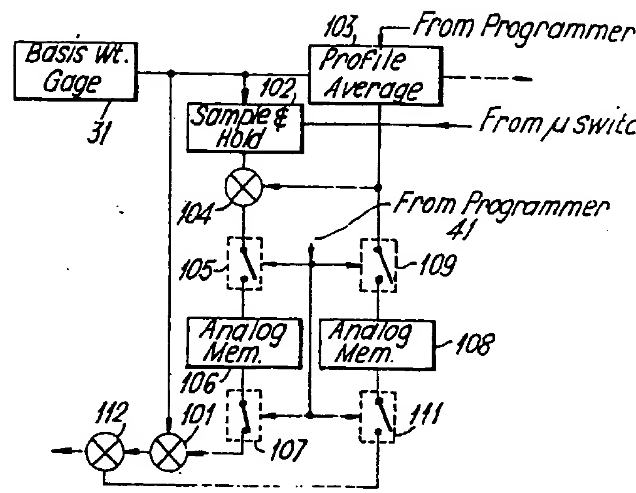
From Programmer
103
Profile Average
Basis Wt. Gage
102
Sample & Hold
31
From μ switch
104
From Programmer 41
105
109
Analog Mem.
Analog Mem.
108
106
112
101
111
107

Fig.3.

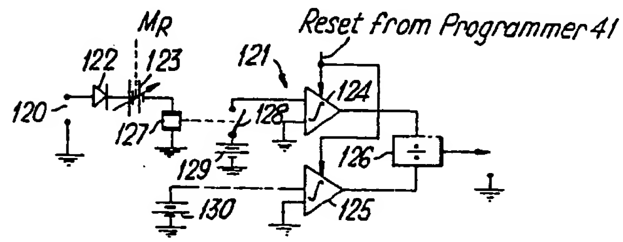
MR
Reset from Programmer 41
122
123
121
124
120
127
128
129
126
130
125

Fig.4.